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Contribution of configural information in a direction discrimination task: Evidence using a novel masking paradigm

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ABSTRACT

Understanding how structure and motion information contribute to the perception of biological motion is often studied with masking techniques. Current techniques in masking point-light walkers typically rely on adding surrounding masking dots or altering phase relations between joints. Here, we demonstrate the use of novel stimuli that make it possible to determine the noise level at which the local motion cues mask the opposing configural cues without changing the number of overall points in the display. Results show improved direction discrimination when configural cues are present compared to when the identical local motion signals are present but lack configural information.

1. Introduction

In humans, the ability to perceive the motions of other animate creatures has been extensively studied and shown to be surprisingly robust. Typically, the study of biological motion has involved using point-light displays that reduce human movement to a small number of moving points placed on the joints. Using this technique Johansson (1973, 1976) showed that when these point-light displays were presented as static frames observers were unable to identify the stimuli. However, when presented dynamically observers immediately recognised the stimuli as representing a human being and could readily identify complex actions. Later research has demonstrated that an extensive number of person properties can be gleaned from these stimuli, including the identity of the actor (Cutting & Kozlowski, 1977; Hill & Pollick, 2000; Jokisch, Daum, & Troje, 2006; Loula, Prasad, Harber, & Shiffrar, 2005; Troje, Westhoff, & Lavrov, 2005) the gender of the actors (Barclay, Cutting, & Kozlowski, 1978; Jordan, Fallah, & Stoner, 2006; Kozlowski & Cutting, 1977, 1978; Pollick, Kay, Heim, & Stringer, 2005; Troje, Sadr, Geyer, & Nakayama, 2006), the emotion of the actors (Clarke, Bradshaw, Field, Hampson, & Rose, 2005; Dittrich, Troscianko, Lea, & Morgan, 1996; Pollick, Paterson, Bruderlin, & Sanford, 2001) and also the nature of the actions being carried out (Dittrich, 1993).

Although the information available in point-light displays supports the recognition of a variety of person properties, the perception of these displays seems particularly affected by temporal manipulations in the local motions of the individual joints that result in disrupted phase relations between the points on the walker (Bertenthal & Pinto, 1994; Grossman & Blake, 1999), and by playing the motion abnormally slowly (Beintema, Oleksiak, & van Wezel, 2006). However, provided the phase relations between the points are preserved and played at a biologically plausible speed, the perceptual system's ability to detect biological motion is surprisingly resistant to distortions of the walker or the embedding of the walker in noise. For instance, limiting the lifetime of the points on the walker or displacing them to points on the skeleton, as opposed to joint locations, barely diminished observers' recognition of point-light walkers (Beintema & Lappe, 2002; Mather, Radford, & West, 1992; Neri, Morrone, & Burr, 1998; Pinto & Shiffrar, 1999). Furthermore, masking the motion of the points using random dynamic noise dots, which is one of the most widely used forms of masking, still does not greatly reduce the impression of a human walkers (Bertenthal & Pinto, 1994; Cutting, Moore, & Morrison, 1988; Ikeda, Blake, & Watanabe, 2005) unless they are used in combination with disruptions in the phase relations between the joints (Hiris, Humphrey, & Stout, 2005). Masking the walker in this way renders local motion cues ineffective for detecting biological motion or discriminating the direction of motion, forcing the perceiver to rely on global or configural cues. Even when the masking dots contain local motion signals identical to those of the walker, large numbers are required to diminish the impression of a human walker (Thornton, Pinto, & Shiffrar, 1998).

As would be expected, spatially scrambling the local motion of the joints to new locations produces a decrease in performance on direction discrimination of locomotion in point-light walkers (Troje & Westhoff, 2006). These disruptions in configural information result in the loss of the perception of global structure from motion

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and reduce the walker to its unordered local motion components. It is argued that this breakdown in configural information is also responsible for the apparent inversion effect seen in biological motion processing (Bertenthal & Pinto, 1994; Pavlova & Sokolov, 2003; Sumi, 1984). Perception of inverted point-light walkers is impaired relative to upright walkers and is independent of the location of the source of gravity (Shipley, 2003; Troje, 2003). However, despite this inversion effect, preservation of certain elements in the display enhances performance in the task. Troje and Westhoff (2006) demonstrated that even when all points but the feet are inverted, observers were still able to accurately discriminate the direction of motion of a point-light walker embedded in a static limited lifetime mask. Furthermore, this effect persists even when the walker is scrambled, although to a lesser extent, arguing for a diminished role of configural cues and a more specialised mechanism that is tuned to the motion of the feet and their relation to gravity.

Although it has been demonstrated that local motion cues alone seem to be able to provide a large amount of information about the direction of locomotion of point-light walkers (Troje & Westhoff, 2006), there have been a number of studies that, using a variety of techniques, have shown the importance of configural cues in biological motion perception. For instance, detection and direction discrimination of point-light walkers seems to be preserved in the absence of local motion cues, such as in the case of the limited lifetime displays used by Beintema and Lappe (2002). In these displays points are randomly selected and made visible on the walker for between two to eight frames before disappearance and replacement by another point. As such, in displays where the lifetime of points is short, such as two or three frames, there is little or no consistent local "image motion". However, observers are still able to recognise the signal as a human moving figure with performance comparable to that with classical point-light stimuli (Beintema & Lappe, 2002). Bertenthal and Pinto (1994) demonstrated that even when masking noise was made up of arm and leg components, participants were able to detect whether a walker was present or absent in a display, suggesting that global form information may be processed prior to local configural elements. In support of this, Pinto and Shiffrar (1999) showed that detection of a walker was impaired when the four limbs were randomly positioned in the same walker space as an intact walker, though performance was still above chance as found with other scrambled walkers (Troje & Westhoff, 2006). Pinto and Shiffrar also compared detection of point-light walkers in visual noise when certain subsets of points were omitted with intact upright and inverted walkers. They found that omission of the central elements of the display (shoulders and hips) resulted in drastic drops in detection of the walkers in dynamic noise masks. Furthermore, detection was not impaired relative to the intact upright walker when the extremities (wrists and ankles) were omitted. This suggests that the central trunk of the walker is more important than the extremities in detecting walkers in noise. Mather and Murdoch (1994), however, found that in a direction discrimination task, the omission of the extremities proved to be the more detrimental condition. These findings together suggest that different tasks call upon different configural properties of the point-light walkers rather than individual local elements. Most studies on configural processing in biological motion have however, used large numbers of masking points to disguise the walkers structure.

In addition to the behavioural evidence on the role of configural cues, a number of recent models have had considerable success in modelling processes involved in biological motion using a combination of configural cues and global motion without a need to resort to local motion. For instance Lange and Lappe (2006) have developed a model of biological motion processing based on existing knowledge of template cells that respond to static postures. The model assumes two stages, one in which the static posture information is sequentially captured by the template cells, though with no knowledge of the temporal order, and a second stage in which the global motion is analysed by explicitly analysing the temporal order for a set of selected frames. Not only is the model neurally plausible, but Lange and Lappe also claim that the model can explain how biological motion processing is achieved in the presence of interfering noise. Furthermore it seems feasible that such a system would be able to deal with the limited lifetime displays of Beintema and Lappe (2002) and also explain why some patients with severe bilateral lesions of MT are capable of seeing biological motion but are unable to integrate low level motion (McLeod, Dittrich, Driver, Perrett, & Zihl, 1996; Vaina, Cowey, LeMay, Bienfang, & Kikinis, 2002). If these models are correct, then it would be expected that tasks such as direction discrimination should be greatly enhanced by the inclusion of configural information and would not rely on sub-configurations or local motion cues to perform tasks such as detection and discrimination of point-light walkers. In support of these models single cell data from monkeys has shown that there are two distinct groups of neurons in the temporal lobe that are selective for static form and motion (Vangeneugden, Pollick, & Vogels, 2009). They found motion selective neurons in the upper fundus of the STS and snapshot neurons (Giese & Poggio, 2003) which were selective for static postures in the lower fundus of the STS and the inferior temporal convexivity. Furthermore, fMRI studies in humans have revealed that the human extrastriate body area and fusiform body areas seem to activate to static images of human postures while areas such as the STS are selective to moving biological displays (Grossman & Blake, 2002; Jastorff & Orban, 2009; Peelen, Wiggett, & Dowling, 2006).

The present study set out to use novel point-light stimuli to examine the specific contribution that configural cues made to the perception of biological motion in a direction discrimination task. These novel stimuli used only the 15 points of a point-light walker and varied the amount of configural information present by dividing them into two subsets. The target subset maintained their original joint locations but were accompanied by dynamic noise that was made up of the remaining points. These non-target points were scrambled to new locations and had their trajectories flipped across the horizontal axis. This ensured all displays had equivalent local motion information and varied only in the amount of configural information present. A second condition was used in which both sets of points were scrambled in space and had opposing trajectories; essentially both signal and noise lacked any configural cues. Although the technique does not exclude the option of manipulating the temporal phase relations between the joints, we chose not to do this in order to examine the specific effect of manipulating the configural information. Participants were asked to judge the direction of motion of the walker and we expected that when configural cues were present accuracy would be higher and performance would improve more sharply. In addition, we modelled the probabilities of certain sub-configurations being present in the signal point group in the configural cues present condition to determine whether these could predict the pattern of results we found.

2. Methods

2.1. Participants

Eleven female and five male undergraduate students (Mean age = 22.4) consented to take part in the experiment. All had normal or corrected to normal vision.

2.2. Experimental design

The task took the form of a two alternative forced-choice direction discrimination paradigm with two conditions: configural cues

present and configural cues absent. There were eight stimulus levels in each condition, which were the number of signal points shown (1, 3, 5, 7, 9, 11, 13, and 15). The number of noise points always equaled 15 minus the number of signal points, ensuring that all stimuli comprised a total of 15 points. There were 20 trials per stimulus level in both conditions giving a total of 320 trials per person.

2.3. Stimuli generation

Stimuli were presented on a CRT monitor with a resolution of 1280×1024 pixels, on a display size subtending 20.4° of visual arc by 15.36° with a refresh rate of 60 Hz at approximately 1 m from the participant. Point-light stimuli were generated from an existing motion capture library (Ma, Paterson, & Pollick, 2006) and displayed and manipulated within the experiment using the Psychophysics Toolbox for MATLAB (Brainard, 1997; Pelli, 1997). The translational motion of the walker was subtracted from the displays so that the walker appeared as if it was walking on a treadmill. Each stimulus was presented for 60 frames (1 s) and showed a full gait cycle. The point-light walkers were scaled to a height of 200 pixels with the resulting figure subtending a visual angle of approximately $3.02° \times 1.32°$ and consisting of white dots on a black background. The points light walkers were randomly jittered horizontally and vertically within a window subtending a visual angle of $5.43° \times 3.70°$. The starting frames of the displays were at the points of minimal distance between the wrist and ankles. This was done as, in experiments without large additional noise masks, this point in a display contains the least amount of configural information making it more difficult to discriminate scrambled displays from intact displays (Thirkettle, Benton, & Scott-Samuell, 2009), which was important in this study in order to minimize any perceptual difference between the conditions other than those of experimental interest.

2.3.1. Configural cues present

Walkers consisted of 15 points and were split at random into two subsets; signal points and noise points. Those in the signal category were selected randomly from the 15 walker points and maintained their existing joint locations and trajectories. The direction of motion of the signal points was randomly varied between leftward and rightward motion. Those points not selected as signal points were spatially scrambled at random to new, available joint locations. Furthermore, the trajectories of the noise points were flipped along the horizontal axis. The resulting displays therefore, had two opposing motion signals, one that preserved configural information (signal points) and another that contained no configural information (noise points). As all points came from the same walker the local motion signal contained in every display was the same, only the quantity of configural information and direction of motion was varied between trials. See Fig. 1 for an illustration of the technique and the supplementary data for examples of the stimuli.

In the specific case in which there was only 1 noise point, and hence no other available location to be moved to, the point had its horizontal coordinate inverted and its trajectory flipped as with all other noise points in other conditions. As such, although not scrambled to a new joint location it was still scrambled in space and provided an incorrect motion signal relative to the signal points. Beyond 1 noise point the number of possible configurations increases exponentially. For instance, in a condition in which there are 3 noise points, given that these noise points can be any of the 15 points at random, there are 2184 possible configurations of these points and by 5 noise points, there are 240240 possible configurations.

2.3.2. Configural cues absent

In the configural cues absent condition the generation of the noise points was exactly the same. However, the signal points were also scrambled to new, free locations but maintained their original trajectories. This produced stimuli with two opposing motion signals with no configural information present in either subset. Thus the only difference in the signal subset between conditions was whether the original joint locations had been preserved or not.

2.4. Procedure

Each participant was instructed to view point-light walkers on the screen. Upon the completion of each stimulus presentation the participant was required to decide whether the walker on the screen was moving from left to right or from right to left using the arrow keys on the keyboard. A correct answer in the configural cues present condition was considered to be when the participant chose the direction of motion of the points with preserved trajectories and joint locations. In the configural cues absent condition a correct answer was operationally defined as when the participant chose the direction of motion of those points that had preserved their original trajectories, in essence the direction of locomotion of the original point-light display. This preserved a scale of proportion correct allowing a direct comparison of performance in both conditions on a scale of 0–1, which would not have been possible with other definitions of "correct" such as the direction with the most overall energy.

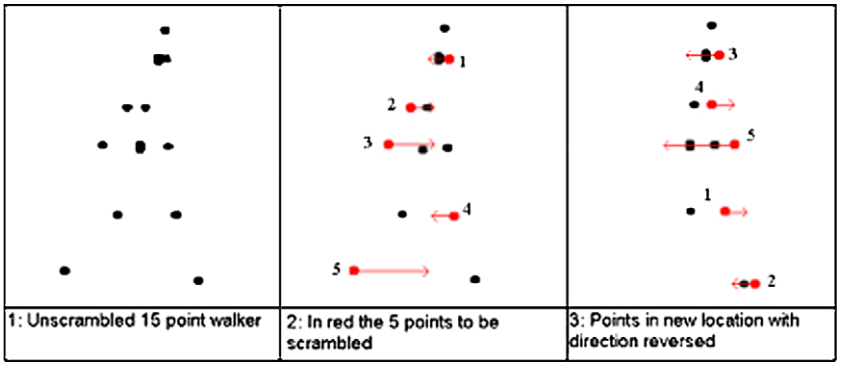

Fig. 1. The first panel depicts the 15 points in a static first frame of an unscrambled point-light walker. The second panel shows the points that are to be scrambled and the original starting trajectories in red. The last panel shows where each of these points is scrambled to and the resulting direction of motion after the trajectories have been flipped (gait and stance have been exaggerated for clarity).

Each participant completed a set of practice trials displaying several levels of stimuli from both conditions. Once a participant had completed these and were comfortable in the task, the main experimental blocks commenced. In both conditions each of the eight stimulus levels were presented once in each of the twenty blocks giving 160 trials per condition. Which condition each participant saw first was counterbalanced to remove any possible order effects. The experiment took just over 30 min to complete.

3. Results

The proportion of correct responses was calculated for each level of stimuli in both conditions for all participants and the data were fitted with a cumulative Gaussian using the psignifit toolbox for MATLAB (Wichmann & Hill, 2001a, 2001b). Slopes and 75% correct thresholds were calculated for each participant and for the group as whole. Two participants were excluded from the analyses as they failed to reach the minimum performance criterions of 75% correct threshold in the configural cues absent condition. Note however that had the two participants been included the difference between the two conditions would have been larger.

Fig. 2 shows the fits for the data averaged across the remaining 14 participants. As can be seen, slopes in the configural information present condition ($m = 0.088$, 95% CI = ±0.006) are steeper than in the configural cues absent condition ($m = 0.056$, 95% CI = ±0.004). Furthermore the 75% correct thresholds in the configural cues absent condition ($m = 12.369$, 95% CI = ±0.463) are higher than those in the configural cues present conditions ($m = 7.748$, 95% CI = ±0.272). *T*-tests on the combined data reveal that these differences were significant (slope $t(13) = 7.155$, $p < 0.001$; 75% threshold $t(13) = 8.732$, $p < 0.001$).

Note also that in the configural cues absent condition performance varies only between 20% and 80% correct. This is to be expected from the results of Troje and Westhoff (2006) as they found that accuracy in a direction discrimination of a scrambled point-light walker was approximately 80%. So in this experiment when all points were moving in the target direction participants responded correctly on 80% of trials, but when almost all the motion was in the opposite direction, participants responded correctly only 20% of the time. This is also the reason that in the configural cues present condition performance does not drop below 20% as these displays are essentially equivalent between the two conditions at 1 signal point.

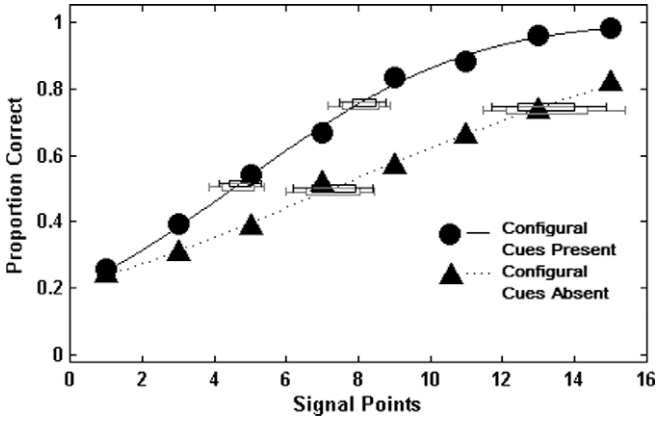

Fig. 2. Circles represent the data points from the configural cues present condition, whilst the solid line represents the best-fit cumulative Gaussian. Similarly, the triangles represent the data points from the configural cues present condition, whilst the broken line represents the best-fit cumulative Gaussian. Error bars are placed at the 50% and 75% thresholds. Dark boxes and lines represent 95% confidence limits and light boxes and bars represent the worst case confidence limits encountered during boot-strapping sensitivity analysis. (Wichmann & Hill, 2001a, 2001b).

3.1. Possible confounding sub-configurations

It is possible that a rule based decision making process based on a sub-configuration of points on the walker could account for the pattern of performance seen in the configural cues present condition. For instance, if a shoulder, elbow and wrist in the correct locations were sufficient to correctly judge the direction of motion then it is likely that the proportion of trials on which these configurations would occur could predict the proportion correct results. Other potential sub-configurations that could influence direction discrimination would be both feet being in the signal group or all three leg points, or arm points, or indeed both arms and legs being in the signal group. Such a strategy would be reliable only when the sub-configuration was present in the signal point category. As such, it is possible to calculate the likelihood that a sub-configuration of k points occurs within the signal point group of size n as defined by

$$\frac{c_k^n}{c_k^{15}} = \frac{(15-k)!n!}{15!(n-k)!} \quad (1)$$

The critical issue here is the likelihood that these sub-configurations are present in the signal subset of points. As the number of signal points increases, so does the likelihood that any sub-configuration is present, and also the likelihood that larger sub-configurations are present. Fig. 3 shows the probability distributions for each potential number of points in a sub-configuration for each level of signal points.

Had participants been consistently using a strategy based on a specific number of points then the pattern of responses would follow the patterns seen in Fig. 3. It is clear however that this is not the case ruling out the use of any specific sub-configuration.

4. Discussion

The results presented above suggest that configural cues play a crucial role in biological motion perception. The 75% correct threshold was significantly higher in the configural cues absent condition than in the configural cues present conditions, indicating that significantly more points were needed to reliably judge the direction of motion in the absence of configural information. In fact, the 75% correct threshold is reached using approximately five fewer points with configural cues than without. Furthermore, the mean slope of the curve in the configural cues present condition was steeper than in the configural cues absent condition indicating that it was not merely the case that it was the number of points that was important, but that each additional point placed in the correct joint location improved performance far more than an additional point placed in a random joint location.

In support of this, looking at the probabilities that any combination of points within the signal point sub-group form any specific sub-configurations that could account for the results, it is clear that the probability distributions shown in Fig. 3 do not match the pattern of results observed in the behavioural data. Had participants been consistently using a specific sub-configuration, or set of sub-configurations of points rather than the global configural cues it would be expected that the behavioural results would be more like the probability distributions than the pattern observed. Some participants did report trying to use a strategy based on tracking the feet or wrist but said that it became too difficult given the short displays and the lack of predictability in the position of the chosen target motion. This makes it unlikely that simple local configurations, such as the two feet being in the correct locations or all

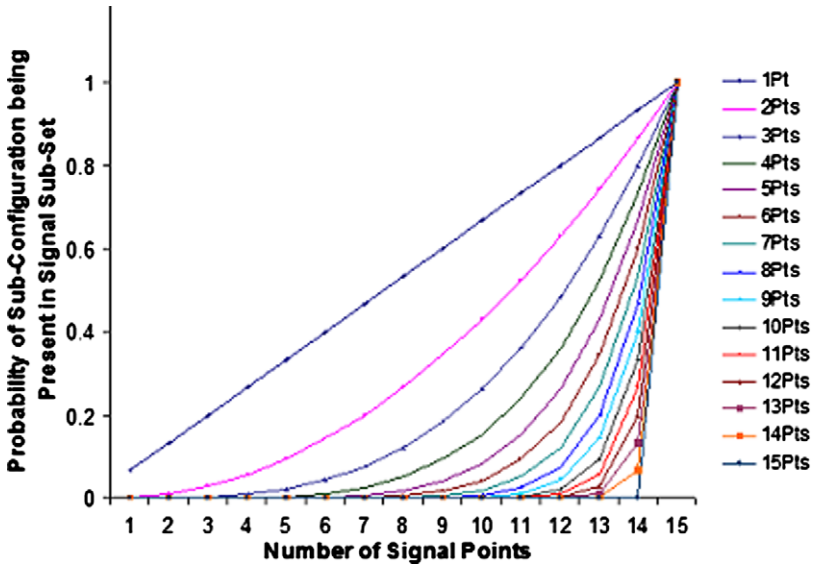

Fig. 3. Probability of a sub-configuration being present given × signal points. Different coloured lines represent sub-configurations of different numbers of points.

arm points being in the correct location, were sufficient to offset the opposing local motion signals without the other signal points that were outside the local configuration. It may be therefore, that, as proposed in recent models (Giese & Lappe, 2002; Lange & Lappe, 2006), there is some sort of template matching combined with temporal analysis that is independent of any simple local motion analysis or analysis of sub-configurations. Indeed, this would seem to be borne out by some of the subjective reports of participants who claimed that on some of the conditions, those in which there was little or no true configural information, they had very occasional impressions of such things as "hula dancers" or "upside down rollerblading", indicating what could be incorrect temporal integration of biologically plausible templates.

This is not to say though, that there are not certain sub-configurations, or indeed local motions, that convey more information than others. It seems likely that the feet and other extremities will convey more information about locomotion than the shoulders or head (Pinto & Shiffrar, 1999; Thurman & Grossman, 2008; Troje & Westhoff, 2006). Moreover, it has been demonstrated that emotions can be partially categorised using just the kinematics of the arm movements (Pollick et al., 2001) and that these kinematic cues can be sufficient to determine emotion in the absence of form information and temporal information, though poorly in comparison to when these cues are present (Atkinson, Tunstall, & Dittrich, 2007). There are also several studies that demonstrate the importance of hip and shoulder swing in gender categorisation (Johnson, Gill, Reichman, & Tassinary, 2007; Mather & Murdoch, 1994). The novel techniques devised for the current experiment may provide a convenient way to examine these relations. It would be possible to specifically manipulate which sub-configurations are present within displays and examine the importance of each in different tasks without the need to use large numbers of masking dots that can differentially engage active and passive attentional mechanisms (Thornton, Rensink, & Shiffrar, 2002; Thornton & Vuong, 2004) or alter phase relations between joints or limbs (Neri, 2009), which essentially disrupts or degrades the coherence of the walkers.

These considerations are particularly important in fMRI studies investigating biological motion processing. For instance Grossman, Blake, and Kim (2004) found that there was a large amount of variance in the number of noise points it took to mask a point-light walker even with training, meaning that to test people at different performance thresholds required displays with differing levels of noise points, and hence motion energy, in each display. The stimuli used in this paper provide a means for testing participants at individual thresholds without having to increase the overall motion signal in the stimuli. This would also make them ideal stimuli for examining sensitivity to biological motion in patients with MT lesions (McLeod et al., 1996; Vaina et al., 2002) and autism spectrum disorders (Frietag et al., 2008; Herrington et al., 2007; Simmons et al., submitted for publication).

In summary, the current experiment has shown that configural information contributes significantly to direction discrimination of point-light walkers. Furthermore, this novel technique allows for the masking of point-light walkers without adding large number of noise dots or disrupting the coherence of the point-light figure and will be useful in future behavioural and neuro-imaging investigations of the role of sub-configurations of points in biological motion processing.

Appendix A. Supplementary material

These are examples of the stimuli used during the experiment for each stimulus level. The actual stimuli used in the experiment were randomly generated and as such each clip below is only an example of one of many different possible combinations of positions of the scrambled points. Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.visres.2009.08.008.

References

Atkinson, A. P., Tunstall, M. L., & Dittrich, W. H. (2007). Evidence for distinct contributions of form and motion information to the recognition of emotions from body gestures. *Cognition, 104*(1), 59–72.

Barclay, C. D., Cutting, J. E., & Kozlowski, L. T. (1978). Temporal and spatial factors in gait perception that influence gender recognition. *Perception & Psychophysics, 23*(2), 145–152.

Beintema, J. A., & Lappe, M. (2002). Perception of biological motion without local image motion. *Proceedings of the National Academy of Sciences of the United States of America, 99*(8), 5661–5663.

Beintema, J. A., Oleksiak, A., & van Wezel, R. J. A. (2006). The influence of biological motion perception on structure-from-motion interpretations at different speeds. *Journal of Vision, 6*(7), 712–726.

Bertenthal, B. I., & Pinto, J. (1994). Global processing of biological motions. *Psychological Science, 5*(4), 221–225.

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision, 10*, 443–446.

Clarke, T. J., Bradshaw, M. F., Field, D. T., Hampson, S. E., & Rose, D. (2005). The perception of emotion from body movement in point-light displays of interpersonal dialogue. *Perception, 34*(10), 1171–1180.

Cutting, J. E., & Kozlowski, L. T. (1977). Recognizing friends by their walk – Gait perception without familiarity cues. *Bulletin of the Psychonomic Society, 9*(5), 353–356.

Cutting, J. E., Moore, C., & Morrison, R. (1988). Masking the motions of human gait. *Perception & Psychophysics, 44*(4), 339–347.

Dittrich, W. H. (1993). Action categories and the perception of biological motion. *Perception, 22*(1), 15–22.

Dittrich, W. H., Troscianko, T., Lea, S. E. G., & Morgan, D. (1996). Perception of emotion from dynamic point-light displays represented in dance. *Perception, 25*(6), 727–738.

Frietag, C. M., Konrad, C., Haberlen, M., Kleser, C., von Gontard, A., Reith, W., et al. (2008). Perception of biological motion in autism spectrum disorders. *Neuropsychologia, 46*, 1480–1494.

Giese, M. A., & Lappe, M. (2002). Measurement of generalization fields for the recognition of biological motion. *Vision Research, 42*(15), 1847–1858.

Giese, M., & Poggio, T. (2003). Neural mechanisms for the recognition of biological movements. *Nature Reviews Neuroscience, 4*(3), 179–192.

Grossman, E. D., & Blake, R. (1999). Perception of coherent motion, biological motion and form-from-motion under dim-light conditions. *Vision Research, 39*(22), 3721–3727.

Grossman, E. D., Blake, R., & Kim, C. Y. (2004). Learning to see biological motion: Brain activity parallels behavior. *Journal of Cognitive Neuroscience, 16*(9), 1669–1679.

Grossman, E., & Blake, R. (2002). Brain areas active during visual perception of biological motion. *Neuron, 35*, 1167–1175.

Herrington, J. D., Baron-Cohen, S., Wheelwright, S. J., Singh, K. D., Bullmore, E. T., Brammer, M., et al. (2007). The role of MT+/V5 during biological motion perception in Aspergers Syndrome: An fMRI study. *Research in Autism Spectrum Disorders, 1*(1), 14–27.

Hill, H., & Pollick, F. E. (2000). Exaggerating temporal differences enhances recognition of individuals from point light displays. *Psychological Science, 11*(3), 223–228.

Hiris, E., Humphrey, D., & Stout, A. (2005). Temporal properties in masking biological motion. *Perception & Psychophysics, 67*(3), 435–443.

Ikeda, H., Blake, R., & Watanabe, K. (2005). Eccentric perception of biological motion is unscalably poor. *Vision Research, 45*(15), 1935–1943.

Jastorff, J., & Orban, G. A. (2009). Human functional magnetic resonance imaging reveals separation and integration of shape and motion cues in biological motion processing. *Journal of Neuroscience, 29*(22), 7315–7329.

Johansson, G. (1973). Visual-perception of biological motion and a model for its analysis. *Perception & Psychophysics, 14*(2), 201–211.

Johansson, G. (1976). Spatio-temporal differentiation and integration in visual-motion perception – Experimental and theoretical-analysis of calculus-like functions in visual data-processing. *Psychological Research – Psychologische Forschung, 38*(4), 379–393.

Johnson, K. L., Gill, S., Reichman, V., & Tassinary, L. G. (2007). Swagger, sway, and sexuality: Judging sexual orientation from body motion and morphology. *Journal of Personality and Social Psychology, 93*(3), 321–334.

Jokisch, D., Daum, I., & Troje, N. F. (2006). Self recognition versus recognition of others by biological motion: Viewpoint-dependent effects. *Perception, 35*(7), 911–920.

Jordan, H., Fallah, M., & Stoner, G. R. (2006). Adaptation of gender derived from biological motion. *Nature Neuroscience, 9*(6), 738–739.

Kozlowski, L. T., & Cutting, J. E. (1977). Recognizing sex of a walker from a dynamic point-light display. *Perception & Psychophysics, 21*(6), 575–580.

Kozlowski, L. T., & Cutting, J. E. (1978). Recognizing gender of walkers from point-lights mounted on ankles – Some 2nd thoughts. *Perception & Psychophysics, 23*(5), 459.

Lange, J., & Lappe, M. (2006). A model of biological motion perception from configural form cues. *Journal of Neuroscience, 26*(11), 2894–2906.

Loula, F., Prasad, S., Harber, K., & Shiffrar, M. (2005). Recognizing people from their movement. *Journal of Experimental Psychology – Human Perception and Performance, 31*(1), 210–220.

Ma, Y. L., Paterson, H. M., & Pollick, F. E. (2006). A motion capture library for the study of identity, gender, and emotion perception from biological motion. *Behavior Research Methods, 38*(1), 134–141.

Mather, G., & Murdoch, L. (1994). Gender discrimination in biological motion displays based on dynamic cues. *Proceedings of the Royal Society of London Series B – Biological Sciences, 258*(1353), 273–279.

Mather, G., Radford, K., & West, S. (1992). Low-level visual processing of biological motion. *Proceedings of the Royal Society of London Series B – Biological Sciences, 249*(1325), 149–155.

McLeod, P., Dittrich, W., Driver, J., Perrett, D., & Zihl, J. (1996). Preserved and impaired detection of structure from motion by a "motion-blind" patient. *Visual Cognition, 3*(4), 363–391.

Neri, P. (2009). Wholes and subparts in visual processing of human agency. *Proceedings of the Royal Society B, 276*, 861–869.

Neri, P., Morrone, M. C., & Burr, D. C. (1998). Seeing biological motion. *Nature, 395*(6705), 894–896.

Pavlova, M., & Sokolov, A. (2003). Prior knowledge about display inversion in biological motion perception. *Perception, 32*(8), 937–946.

Pelli, D. H. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10*, 437–442.

Peelen, M. V., Wiggett, A. J., & Dowling, P. E. (2006). Patterns of fMRI activity dissociate overlapping functional brain areas that respond to biological motion. *Neuron, 49*, 815–822.

Pinto, J., & Shiffrar, M. (1999). Subconfigurations of the human form in the perception of biological motion displays. *Acta Psychologica, 102*(2–3), 293–318.

Pollick, F. E., Kay, J., Heim, K., & Stringer, R. (2005). Gender recognition from point-light walkers. *Journal of Experimental Psychology: Human Perception and Performance, 31*(6), 1247–1265.

Pollick, F. E., Paterson, H. M., Bruderlin, A., & Sanford, A. J. (2001). Perceiving affect from arm movement. *Cognition, 82*(2), B51–B61.

Shipley, T. F. (2003). The effect of object and event orientation on perception of biological motion. *Psychological Science, 14*(4), 377–380.

Simmons, D. R., Robertson, A. E., McKay, L. S., Toal, E., McAleer, P., & Pollick, F. E. (submitted for publication). Vision in autism spectrum disorders. *Vision Research*.

Sumi, S. (1984). Upside-down presentation of the Johansson moving light-spot pattern. *Perception, 13*(3), 283–286.

Thirkettle, M., Benton, C. P., & Scott-Samuell, N. E. (2009). Contribution of form, motion and task to biological motion. *Journal of Vision, 9*(3), 1–11.

Thornton, I. M., Pinto, J., & Shiffrar, M. (1998). The visual perception of human locomotion. *Cognitive Neuropsychology, 15*(6–8), 535–552.

Thornton, I. M., Rensink, R. A., & Shiffrar, M. (2002). Active versus passive processing of biological motion. *Perception, 31*(7), 837–853.

Thornton, I. M., & Vuong, Q. C. (2004). Incidental processing of biological motion. *Current Biology, 14*(12), 1084–1089.

Thurman, S. M., & Grossman, E. D. (2008). Temporal "Bubbles" reveal key features for point-light biological motion perception. *Journal of Vision, 8*(3), 1–11.

Troje, N. F. (2003). Reference frames for orientation anisotropies in face recognition and biological-motion perception. *Perception, 32*(2), 201–210.

Troje, N. F., Sadr, J., Geyer, H., & Nakayama, K. (2006). Adaptation aftereffects in the perception of gender from biological motion. *Journal of Vision, 6*(8), 850–857.

Troje, N. F., & Westhoff, C. (2006). The inversion effect in biological motion perception: Evidence for a "life detector"? *Current Biology, 16*(8), 821–824.

Troje, N. F., Westhoff, C., & Lavrov, M. (2005). Person identification from biological motion: Effects of structural and kinematic cues. *Perception & Psychophysics, 67*(4), 667–675.

Vaina, L. M., Cowey, A., LeMay, M., Bienfang, D. C., & Kikinis, R. (2002). Visual deficits in a patient with 'kaleidoscopic disintegration of the visual world'. *European Journal of Neurology, 9*(5), 463–477.

Vangeneugden, J., Pollick, F., & Vogels, R. (2009). Functional differentiation of macaque visual temporal cortical neurons using a parametric action space. *Cerebral Cortex, 19*(3), 593–611.

Wichmann, F. A., & Hill, N. J. (2001a). The psychometric function: I. Fitting, sampling and goodness-of-fit. *Perception & Psychophysics, 63*(8), 1293–1313.

Wichmann, F. A., & Hill, N. J. (2001b). The psychometric function: II. Bootstrap-based confidence intervals and sampling. *Perception & Psychophysics, 63*(8), 1314–1329.